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RESEARCH ARTICLE

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Status of phytoplankton biomass and physico-chemical parameters of water during fish cage culture fallowing: a case study of Southeast Arm of Lake Malawi

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ABSTRACT

The prospect of using fallowing as an ecosystem management measure to restore ecosystem functions in disturbed aquatic environments under cage culture was evaluated in this study. The cage aquaculture site in the Southeast arm of Lake Malawi was studied following the abandonment of cage aquaculture activities in 2022 after 18 years of operation. A Hydrolab CTD MS5 series probe was cast at each station to a maximum depth to collect electronic data and provide *in situ* depth profiles of temperature, dissolved oxygen, oxygen saturation, pH and salinity. Chlorophyl-extraction was done using a mixture of acetone and methanol and analyzed on a turner series 10 fluorometer. The study found that physical-chemical parameters such as temperature, pH, ammonia, turbidity and dissolved oxygen were not significantly different ($p > 0.05$) across the cage and non-cage sites and between seasons. However, ammonia levels recorded in this study were lower than the values reported during the cage culture operations period, an indication that some recovery processes are happening at the site. Chlorophyl a level was found to be insignificantly higher in cage and non-cage sites ($p > 0.0.5$) and significantly different between season ($p < 0.05$). High levels of Chl-a observed in this study are independent of cage aquaculture but might be linked to external inputs associated with tributaries as they collectively drain into the lake. Chl-a was found to be significantly and directly correlated to temperature, followed by total suspended solids and pH. Overall, the site is undergoing recovery with respect to the abandonment, but the effect is masked by external inputs of nutrients into the Lake. Although the study confirmed the oligotrophic status of the lake, the increasing levels of Chl-a are alarming and calls for inclusion of watershed management in agriculture and environmental management programming to sustainably safeguard the health of the Lake.

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1. Introduction

In the face of declining fishery resources caused by pressures from a growing human population, unsustainable fishing practices, climate-related shocks, and environmental degradation, the urgency for diversified sources of fish protein has become increasingly critical (Yee et al. 2012; Maulu et al. 2021, Muhala et al. 2021a; Maulu et al. 2024). Aquaculture has emerged as a viable alternative source of food, animal protein, and livelihood, with strong promotion from both Non-Governmental Organizations (NGOs) and governments to address challenges such as unemployment and malnutrition (Maulu et al. Hasimuna et al. 2023; Langi et al. 2024). Within the aquaculture sector, cage aquaculture has proven to be a promising approach, particularly in developing countries like Malawi, where it plays a vital role in enhancing fish production and sustaining the growing population (Hasimuna et al. 2019; Muhala et al. 2021b; Simfukwe et al. 2024).

Initially introduced at Maldeco Aquaculture Farm in Mangochi, Lake Malawi, cage aquaculture has since spread to other lakeshore districts and small water bodies across Malawi. However, this expansion has brought concerns about environmental degradation, especially in the absence of stringent guidelines or adherence to existing best practices (Devi et al. 2017). Key environmental impacts include the reduction of available water surface area, changes in water flow, and nutrient input from the cages leading to organic enrichment of the surrounding water and sediments, and alteration of macrofauna communities (Zhulay et al. 2015; Hasimuna et al. 2021). These changes are primarily driven by the release of organic matter in the form of mineral nutrients in feed, faeces, and uneaten feed from the cages (Macleod et al. 2006; Hasimuna et al. 2019, 2024).

Phytoplankton, particularly through the measurement of chlorophyll-a (Chl-a), is a valuable indicator of nutrient enrichment and water quality (Maslukah et al. 2022). Chl-a concentration is commonly used to assess phytoplankton biomass and classify aquatic environments according to their trophic status (El-Serehy et al. 2018). Research has shown that Chl-a levels can be significantly affected by cage aquaculture activities. For example, in Batang Ai Reservoir, despite the cessation of cage aquaculture for nine months, Chl-a levels remained elevated, indicating persistent mesotrophic conditions (Ling et al. 2016). Similarly, in the Southern Caspian Sea, higher phytoplankton communities were observed at cage aquaculture sites compared to control stations, suggesting long-term, possibly irreversible effects on the ecosystem (Afraei Bandpei et al. 2016).

On Lake Malawi, early monitoring of cage aquaculture began during its nascent stages in 2006/07, with a production of approximately 200 tons annually, which increased to 800 tons by 2011/12. These assessments revealed that Chl-a concentrations rose from below 1 μg/L in the initial assessment to above 1 μg/L in subsequent years, suggesting that cage aquaculture contributed to increased phytoplankton biomass (Bootsma and Hecky 1993; Gondwe et al. 2011; Macuiane et al. 2016). Although the differences in Chl-a levels were not statistically significant, the concentrations were higher at cage sites compared to locations 5-10 km away, with strong seasonal variations observed (Ma et al. 2019).

In 2022, cage aquaculture was suspended in the Southeast Arm of Lake Malawi. In other regions, studies have explored the potential for ecological recovery following the cessation of cage aquaculture activities, a process known as fallowing (Macleod et al. 2006; Zhulay et al. 2015). The success of fallowing as a management strategy depends on several factors, including nutrient load intensity, water currents, depth, and other environmental conditions. Considering the unique characteristics of each aquatic ecosystem, site-specific assessments are critical to determine the feasibility of fallowing. This study aimed at assessing phytoplankton biomass, as indicated by Chl-a, and physicochemical water quality parameters to evaluate the biological recovery of a cage aquaculture site after fallowing. The findings of this study will be valuable for the sustainable management of waterbodies under similar situations.

2. Materials and methods

The study was conducted at the Southeast Arm of Lake Malawi in Mangochi within the Foods Company Limited, Maldeco aquaculture farm (Figure 1). The farm was established in 2003 covering an area of about 14 hectares and has a land and lake-based fish culture facilities. Land based facilities are for fingerling production. The fingerlings are then transferred and stocked to the lake-based system (cages) for grow out in existing 67 cages which are approximately 16 m in diameter and a total volume of 1200 m^3 each.

The cages were installed about 1 km from the shore at a water depth of about 20 meters. The farm was raising *Oreochromis shiranus* at a density of 66 fingerlings per m^3 translating to 80,000 fingerlings per cage. The samples for physical-chemical and phytoplankton biomass analysis were collected from the cage sites and non-cage sites. The two non-cage sites representing the reference stations were located 2.5 km away (one in the northwest and the other southeast) from the cage site.

2.1. Analysis of physico-chemical water quality parameters

A boat powered by a 15 Hp outboard Yamaha engine was used to navigate the sampling points. An integrated Global Position System (Garmin *Etrex* GPS) and a GPS map 178C Sounder fitted with a transducer to collect depth (m) information and corresponding position in decimal degrees of Longitude and Latitude was also used. A Hydrolab CTD MS5 series probe was cast at each station to a maximum depth to collect electronic data and provide *in situ* depth profiles of temperature, dissolved oxygen, oxygen saturation, pH and salinity. Ammonia was analysed according to APHA (2012). Turbidity measurements were carried out using a Turbidimeter calibrated with 100NTU standard solution. A 30 cm diameter black and white secchi disk was used to determine an average transparency of the lake water in all the sampled stations where CTD was cast.

2.2. Determination of phytoplankton biomass using chlorophyll-a

Sampling was conducted between 06:00 and 10:00 h to minimize the influence of diurnal variations on chlorophyll-a concentrations. Surface water samples were collected at a depth of 0.5 meters, then subsequent water samples were collected from depths of 8 and 16 meters using a 5-l Niskin water sampler. Approximately 1 L of this sample was filtered through 47 mm diameter GF/F Whatman filter paper for chlorophyll-*a* analysis. Filters for chlorophyll *a* were wrapped in aluminum foil and kept at -20^0C before analysis at the Senga Bay Fisheries laboratory. At the laboratory, Extraction of chlorophyll a was carried out in a 10-mL mixture of acetone (27%), methanol (68%) and water (5%) (Stainton et al. 1977). Chlorophyl-a measurement was done on a Turner Series 10 fluorometer.

The sample extracts were then transferred to the fluorometer cuvette by carefully pipetting and then measured against a 90% acetone blank. 0.2 ml 1% v/v hydrochloric acid was added in the curvette, appropriately mixed, left for 2–5 min, and then measured again against a 90% acetone blank. Chl-a was determined according to the equation of Holm-Hansen et al. (1965).

3. Results

3.1. Physical-chemical parameters of water

Variation in dissolved oxygen were observed across the sampling stations with higher concentrations at the non-cage site in the Northwest and the lowest at the cage site (Table 1). Temporal observation revealed that higher DO levels were associated with the dry season in August. The highest average temperature levels were observed at the non-cage site in the Southeast station and lowest at the non-cage site in the Northwest station (Table 1). Comparing the seasons, higher temperature levels were recorded during the wet season in February.

Like temperature, high total suspended solids were observed at the non-cage site (Southeast) while the non-cage site (Northwest) recorded the lowest TSS level (Table 1). Seasonal variation was observed as the wet season recorded high TSS levels across the stations. Turbidity was highest at non-cage site in southeast station followed by the non-cage site in the Northwest, the least being cage site (Table 1). The wet season recorded the highest turbidity levels across the stations. The highest overall pH levels were observed at non-cage site in the Northwest and the lowest at the cage site station (Table 1). Comparing the sampling time, the dry season had the highest pH levels across all stations with the Southeast station showing the highest pH levels followed by the cage site then Northwest as the lowest (Table 1).

Regardless of sampling location and sampling time, salinity levels were observed to be equal at all locations and seasons. Overall, ammonia levels were high at the non-cage site in the Northwest station followed by the non-cage site in the Southeast and lowest at the cage site. Ammonia levels differed in sampling times across all the three locations as the cage site had high ammonia levels during the wet season but non-cage sites in Southeast and Northwest had low ammonia levels during the wet season. Total phosphorus was undetectable in water samples collected across all stations during the dry season, but the wet season sample were not analyzed due to contamination.

Despite the variation across sampling stations, no significant differences were observed in all water quality parameters across the sampled stations (Table 3).

The association between physical chemical variables at the cage aquaculture site revealed the highest positive correlation between turbidity and TSS, followed by a negative Dissolved oxygen and temperature association (Table 4). A weak negative association was observed between pH and turbidity.

3.2. Phytoplankton biomass after cessation of cage aquaculture in the southeast arm of Lake Malawi in Mangochi

Phytoplankton biomass indicated by Chlorophyll a (Chl-a) varied across the sampling station with the non-cage site 1 (Northwest station) having the overall phytoplankton biomass of 2.35 mg/l, followed by non-cage site 2 (Southeast station) at 2.31 mg/l and last cage site at 2.10 mg/l. According to Figure 2 (because figure 1 is the map showing location where the research was conducted) Figure 1, the wet season had the highest Chl-a concentration than the dry season across all sampling stations.

In terms of depth, Southeast station had the highest surface Chl-a concentration during the dry season followed by Northwest then the cage site (Figure 2). Surface Chl-a concentration during the wet season was equal for Southeast and Northwest station but the cage site had the lowest levels.

Overall, a decreasing trend was observed in Chl-a concentration as depth was increasing across all the sampling stations and regardless of sampling time (season) except for the dry season at the cage site where the surface Chl-a level was the lowest compared to Chl-a at 8 meters and 16 meters (Figure 2).

Table 1. Selected water quality parameters at a cage site on lake Malawi one year after cessation of fish farming.

Location	Season	DO (mg/l)	Temp (^{0}C)	TSS (mg/l)	Turbidity (NTU)	pH	Salinity (ppt)	Ammonia (mg/l)	Chl-a (µg/l)
Cage site	Wet	8.06	29.57	16	10	7.25	0.12	0.13	2.35
	Dry	8.66	23.89	0	0.01	8.39	0.12	0.08	0.93
	Mean	*8.36 ± 0.42*	*26.73 ± 4.02*	*8 ± 11.31*	*5.01 ± 7.06*	*7.82 ± 0.81*	*0.12 ± 0*	*0.11 ± 0.04*	*1.64 ± 1.00*
Southeast	Wet	8.13	29.45	22	18	7.43	0.12	0.11	2.72
	Dry	8.75	24.27	0	0.01	8.77	0.12	0.13	0.95
	Mean	*8.44 ± 0.44*	*26.86 ± 3.66*	*11 ± 15.56*	*9.01 ± 12.72*	*8.1 ± 0.95*	*0.12 ± 0*	*0.12 ± 0.01*	*1.84 ± 1.25*
Northwest	Wet	8.16	29.37	12	11	7.74	0.12	0.07	2.37
	Dry	8.88	23.76	0	0.01	8.36	0.12	0.19	1.16
	Mean	*8.52 ± 0.51*	*26.57 ± 3.97*	*6 ± 8.49*	*5.51 ± 7.77*	*8.05 ± 0.44*	*0.12 ± 0*	*0.13 ± 0.08*	*1.77 ± 0.86*

Table 2. Selected water quality parameters of water during cage aquaculture operations at a cage aquaculture site in 2007 and 2012. Source: (Gondwe, 2011; Macuiane, 2016).

Water quality parameters	Sampling site	2007	2012
Temp	Cage site	25.8	25.85
	Non-cage SE	25.75	25.75
	Non-cage NW	25.9	25.95
Ch-a	Cage site	0.9	1.58
	Non-cage SE	0.81	1.85
	Non-cage NW	0.83	1.31
NH_4^+	Cage site	8	
	Non-cage SE	8.3	
	Non-cage NW	8.1	
TSS	Cage site	1.67	
	Non-cage SE	1.22	
	Non-cage NW	1.38	
DO	Cage site	7	7.25
	Non-cage SE	6.8	7.35
	Non-cage NW	6.9	7.6
Secchi Depth	Cage site	5.7	6
	Non-cage SE	6.1	5.6
	Non-cage NW	5.9	5.75

Table 3. Kruskall–Wallis analysis to determine the differences in physical and chemical parameters of water across sampling stations after cessation of cage aquaculture in the southeast of lake Malawi in Mangochi.

Parameter	Total N	Test Statistic	Degrees of freedom	Asymptotic sig (2-sided test)
Temperature	6	0.857	2	0.651
Dissolved Oxygen	6	1.143	2	0.565
Total Suspended Solids	6	0.323	2	0.851
Turbidity	6	0.323	2	0.851
pH	6	0.286	2	0.867
Salinity	6	0.000	2	1.000
Ammonia	6	0.074	2	0.964

Significance level at 0.05.

Table 4. Correlation between physical-chemical factors at cage aquaculture site in the southeast arm of lake Malawi in Malawi.

		DO	Temp	pH	Turbidity	TSS	Chl-a
DO	Pearson Correlation	1	−0.981	.928	−0.900	−0.928	−0.938
	Sig. (2-tailed)		<.001	.008	.014	.008	.006
Temp	Pearson Correlation		1	−0.926	.929	.945	.976
	Sig. (2-tailed)			.008	.007	.005	<.001
pH	Pearson Correlation			1	−0.876	−0.929	−0.935
	Sig. (2-tailed)				.022	.007	.006
Turbidity	Pearson Correlation				1	.983	.974
	Sig. (2-tailed)					<.001	.001
TSS	Pearson Correlation					1	.975
	Sig. (2-tailed)						<.001

Despite the variations observed in Figure 2, there were no significant differences in the distribution of Chl-a across all the sampling stations (Table 5). Significant differences were observed in relation to sampling time where the wet season differed significantly in Chl-a levels with the dry season across the sampling stations (Table 5).

3.3. Relationship between physical chemical variables and phytoplankton biomass at a cage aquaculture site on Lake Malawi

A correlation analysis revealed that Chl-a was highly influenced by temperature, showcasing a positive relationship Table 4 (Table 3). Total suspended solid was identified as the

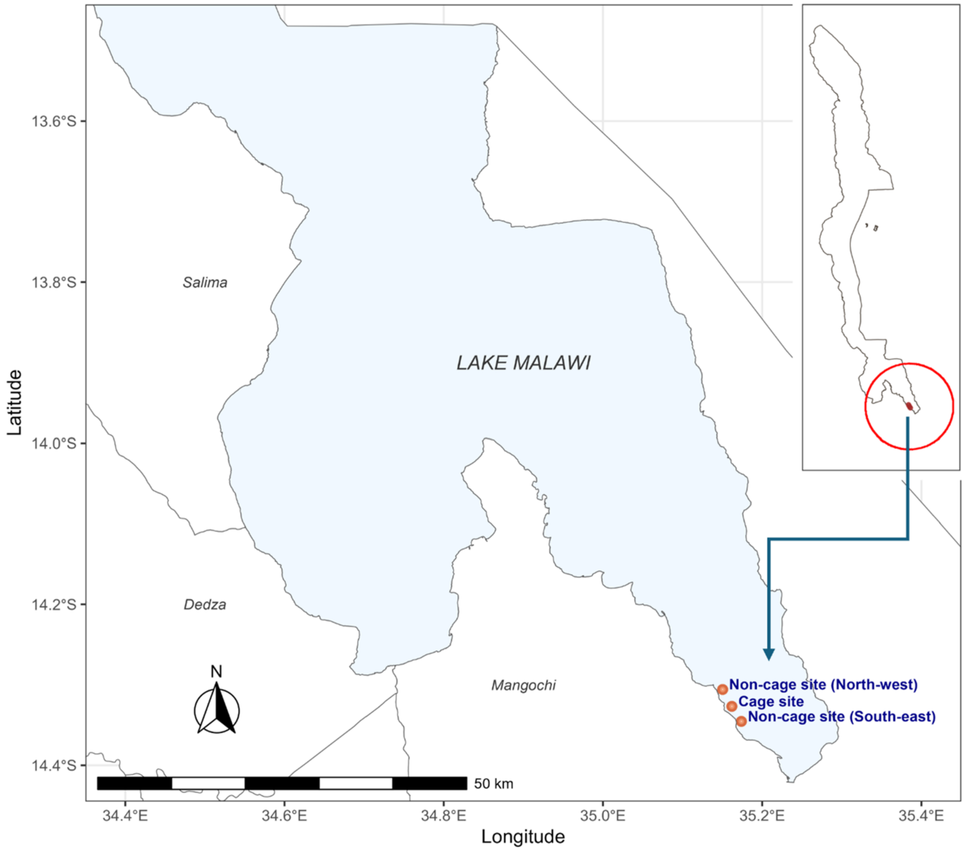

Figure 1. Map of Lake Malawi showing the Southern tip of the Lake where cages were located and samples collected.

Table 5. Effect of sampling location and time on phytoplankton biomass (Chl-a) after cessation of fish farming on lake Malawi.

Source of Variation	SS	Df	MS	F	P-value	F crit
Location	0.116558	2	0.058279	0.198672	0.822462	3.885294
Season	9.698377	1	9.698377	33.06165	9.16E-05	4.747225
Interaction	0.243381	2	0.12169	0.414841	0.669564	3.885294
Within	3.520107	12	0.293342			
Total	13.57842	17				

second most influential factor on Chl-a, having a positive association as well. The third most influential factor was turbidity which again exhibited a positive association. Dissolved oxygen was the fourth most influential factor and demonstrated a negative association.

4. Discussion

4.1. Physical-chemical parameters of water after cessation of cage aquaculture

Dissolved oxygen is very important for sustenance of life in the aquatic ecosystem. Because of this it has been used as an indicator of water pollution in areas with cage aquaculture activities (Devi et al. 2017). Among the three sampled sites, the cage site had the lowest dissolved oxygen levels compared to the sites with no cages despite that

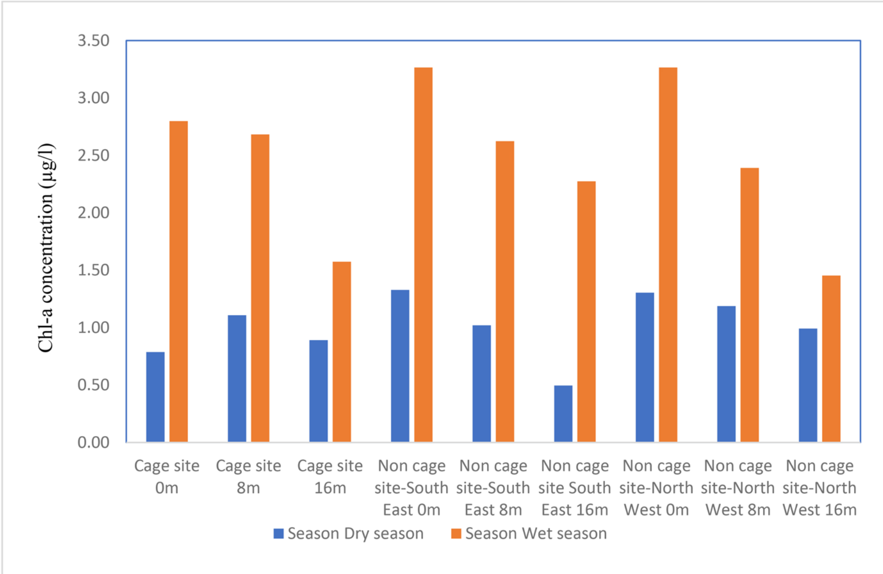

Figure 2. Spatio-temporal differences in phytoplankton biomass (Chl-a) at a cage aquaculture site in the southeast arm of lake Malawi.

differences were not significant. The low levels at the cage site may be attributed to cage aquaculture activities which were happening at the site for the past two decades, releasing organic wastes in form of uneaten feed and faeces from the fish. A study at Kenjeran coastal water in Surabaya, east Java, Indonesia found DO levels of <5mg/l and attributed this to high input and organic wastes (Mahenda et al. 2021). These organic wastes disintegrate releasing nitrogen and phosphorus which facilitate the proliferation of phytoplankton which deplete oxygen at night (Kaunda et al. 2023). Further to this, a population of wild was observed at the cage site but not at the other two sites, suggesting that they could contribute to oxygen consumption at the site.

Dissolved oxygen observation from this study are within the acceptable levels of >4mg/l for freshwater environments (Kaunda et al. 2023). In comparison to studies done when cage aquaculture was active at the site, dissolved oxygen levels observed in this study regardless of the site sampled are higher than those of the previous researchers (Gondwe, 2011; Macuiane, 2016). This is a reflection that some biological recovery may have been happening since cage aquaculture activities ceased at the site. Further to this, the results from this study are comparable to the 8.4 mg/l average for Sani Maganga and 8.35 mg/l for Chilambula site on Lake Malawi in Salima reported by a feasibility study for potential areas for cage aquaculture (Kaunda et al. 2023). These findings cement the thought that a break in cage aquaculture activities for a certain period may result in the ecology of the site recovering from the disturbances.

In terms of seasonal changes, the findings from this study are similar to the previous reporters who studied the site during cage operation and observed that dissolved oxygen was high in august and decreased with time, as low levels were observed in February (Macuiane et al. 2016). This information is important to farm management practices as farm managers can prepare for periods which the farm site has high or less oxygen and institute appropriate actions like reducing the number of stocked fish in a cage through intermittent harvesting or reducing the number of stocked cages to match with oxygen conditions at the site.

Temperature influences oxygen saturation in the aquatic environment and is also responsible for fish production as it controls several biochemical processes such as oxygen consumption, metabolic activities and feed conversion (Kaunda et al. 2023). This study did not record any significant differences in water temperatures across the study sites at all sampling periods. The high water temperatures in February and low water temperatures recorded in August are similar to the findings reported by previous researchers who studied the site when cage aquaculture activities were in progress (Gondwe et al. 2011; Macuiane et al. 2016). This trend is typical when transitioning from the warm-rainy period (Dec to April) to the cool-windy mixing period on the lake (May to September) and the warm post mixing period (October to December). The temperature levels recorded in this study are within the acceptable range of 26 °C–31 °C for optimal warm water fish production (Boyd, 1990).

High total suspended solids reduce the penetration of light in the water and affects the photosynthetic activities by phytoplankton and other aquatic plants (Devi et al. 2017). This has consequences on the concentration of dissolved oxygen in water. Despite no significant differences in TSS values across the sampled sites, the wet season recorded high levels of total suspended solids that the dry season. This also resonates with the low oxygen levels in the wet season compared to the dry season.

The low TSS at the cage site compared to Southeast station is an indication that the ecosystem has been recovering from the ecological disturbances because previous researchers recorded high values of TSS at cage site compared to the other sites, which they attributed it to fish excretion and excess feed (Gondwe et al. 2011; Macuiane et al. 2016). Overall, the values of TSS recorded in this study are higher than those recorded in the previous studies done at the same site when cage aquaculture was active, suggesting that there are other sources of TSS on the lake other than cage aquaculture which are contributing to the increase in TSS during the wet season. Gondwe et al. (2011) observed a decline in TSS between September to December and an increase from the end of December, attributing this to inputs from tributaries. The results are also comparable to those reported by a feasibility study for cage aquaculture on Lake Malawi in Salima and within the acceptable standard of 10–15mg/l (Kaunda et al. 2023).

The cage site had the highest clarity compared to the other sites despite the differences not being significant. The low turbidity levels can be attributed to the recovery process facilitated by the break in cage aquaculture activities. In agreement to this thought, the secchi depth of 4–5 m recorded in this study is similar to the values reported for sites on Lake Malawi in Salima which were ear marked by the feasibility study as potential sites for cage aquaculture (Kaunda et al. 2023). On the contrary, the previous studies done at Maldeco conducted when the fish cages were active reported high turbidity levels at Maldeco middle station which is different from the current findings. This cement the thought that the positive attribute of resting a cage aquaculture farm site for a defined period is site recovery from ecological disturbances emanating from organic matter enrichment. The high turbidity values during the wet season resonates with the low secchi depth which was observed during the same season. Although this is uniform for the current studied sites, it contradicts the findings by Gondwe (2011) who reported that only South station exhibited high secchi depth during the wet season and low in the dry season which was vice versa for the north stations, while the cage site remained similar in both seasons.

Waste deposits from fish cages may cause the pH to drop (Devi et al. 2017). The optimum pH range for fish growth is 7.0-8.5 (Kaunda et al. 2023). pH levels observed in this study are alkaline and within the acceptable range. Fish are susceptible to stress and pathogen attacks when the water conditions are acidic because most fish thrive at pH levels above 7.0 (Kaunda et al. 2023). Similar alkaline pH conditions have been reported at Sani Maganga, Chibolo, Makukuta and Chilambula sites on Lake Malawi in Salima which are areas never exposed to cage aquaculture (Kaunda et al. 2023). However, pH levels for the dry season were higher than that of the wet season. This could be an effect of tributaries flowing through the lake during the rainy season which bringing inputs like organic matter which increase the biological oxygen demand as they decompose, releasing carbon dioxide which forms carbonic acid when it mixes with water hence reducing the pH (Devi et al. 2017). This agrees with what was reported in Kenjerani coastal waters in Surabaya, East Java Indonesia that the observed (Mahenda et al. 2021) low pH was due to household waste.

The insignificance of pH across the study sites is an indication that the sites are ecologically similar despite one being exposed to nutrient discharge disturbances. This similarity is suggested to be facilitated by recovery process considering that previous studies reported significant differences in pH. Carbon dioxide released from food decomposition and respiratory activities form carbonic acid when it mixes with water, creating acidic conditions (Devi et al. 2017). In absence of cage aquaculture, there is less organic matter released in form uneaten feed and faeces to be decomposed.

This study, just like the previous studies, did not find any significant differences in ammonia concentrations across all sites. The current findings also agree with previous reports that ammonia levels were low for the cage site compared to the north and south station (Gondwe et al. 2011). Generally, the ammonia levels presented in this study are low compared to the previous research and within the acceptable levels of <0.5 mg/l (Gondwe et al. 2011; Macuiane et. 2016; Kaunda et al. 2023). The low levels agree with the philosophical thought that in absence of fish farming activities, the site may be undergoing biological recovery.

4.2. Phytoplankton biomass after cessation of cage aquaculture in the southeast arm of Lake Malawi

Phytoplankton occupies the base of the food web in the aquatic environment acting as primary source of energy transfer to aquatic organisms. Phytoplankton biomass can also be used to determine the trophic status of an aquatic environment (Ling et al. 2016; Maslukah et al. 2022). Because of this, phytoplankton has been used as an indicator for monitoring the quality of aquatic environments especially where there is discharge of nutrient inputs.

The findings on Chl-a from this study agree with the observation by previous researchers who also found no significant differences in Chl-a values across all study sites (Gondwe et al. 2011; Macuiane et al. 2016). However, overall Chl-a values observed in this study are higher than those observed by Gondwe et al. (2011) and Macuiane et al. (2016) when cage aquaculture production was ~200 tones and ~800 tons per year. The current overall increase might also be an effect of increased production to ~1000 tons per year at a time when cage operation was terminated. In terms of seasonal effect on Chl-a, Macuiane et al. (2016) reported that values of Chl-a in wet season in February were higher than those of the dry season in August. This study also made similar observation which revealed that season had a significant effect on Chl-a values.

The increasing trend of lake productivity from the dry season to the rainy season is an indication that productivity is fueled by other external input sources of nutrients other than fish farming since the observations in this study were made when the site was abandoned for cage aquaculture, unlike during the time of the other previous studies. In cementing this thought, although the values were higher than those for the previous researchers, the abandoned cage site had low Chl-a compared to the other two sites an indication that cage aquaculture did not have influence on the Chl-a values as the cage site was rested for six months to one year. In the previous studies, Chl-a values at the cage aquaculture site were higher than the two reference sites (Gondwe et al., 2011). Reporting low Chl-a values at a cage aquaculture site which has been abandoned in this study points out to the possibility of using site abandonment for ecological restoration of a disturbed site by cage aquaculture activities.

Bootsma and Hecky (1993) concluded that nutrient pool in Lake Malawi is contributed by other sources such as land clearing and erosion. This has also been highlighted by the two previous researchers who researched the cage site (Gondwe et al., 2011; Macuiane et al. 2016). However, the highest Chl-a reported by previous researchers was May and April for the studies done in 2007 and 2011 respectively (Gondwe et al. 2011; Macuiane et al. 2016). The peak levels were attributed to mixing period leading to resuspension of algal. The limitation in comparison is that in the current study there was no month-to-month sampling thus absence of April and May Chl-a levels makes it difficult to conclude that the high levels observed during the wet season in February can already be attributed to upwelling despite approaching the months where upwelling is prominent.

Another unique observation is that Chl-a values observed during the dry and wet season are higher than those reported by previous studies for the same period when cage aquaculture operations were operational at the site (Macuiane et al. 2016). Chl-a values from this study are also higher than those reported for Sani Maganga (1.03 μg/l), Chilambula (0.73 μg/l) and other sites on Lake Malawi in Salima district (Kaunda et al. 2023). This agrees with the thought that there are inputs from other sources into the lake. However, it also brings a new perspective that Chl-a alone would not be a good parameter to be solely used when monitoring ecological restoration of a cage aquaculture site on Lake Malawi since it is highly influenced by other factors as observed in this study that it increased even when there were no cage aquaculture activities. In contrast to the findings from this study, despite being abandoned for 9 months, phytoplankton biomass was still high at an aquaculture site in Malaysia though not as high as the areas with cage aquaculture activities in operation (Ling et al. 2016). The low values at the abandoned site indicate that some ecological restoration was happening though slowly to conclude that 9 months was enough to see a desirable restoration.

Based on the Chl-a levels of <3μg/l and water clarity of >3.9 m, the trophic status of the study sites is classified as oligotrophic (El-Serehy et al. 2018). Previous researchers classified Lake Malawi as typical oligotrophic when they observed Chl-a values of less than 1 μg/l which is different from this study as it recorded Chl-a values greater than 1 but less than 3 μg/l (Bootsma and Hecky 1993; Gondwe et al. 2011; Macuiane et al. 2016; Kaunda et al. 2023). These results are also different from the findings of an abandoned site, Batang Ai water reservoir in Malaysia which was still mesotrophic just like the areas with cage aquaculture activities, suggesting that the recovery process was slow, and 9 months was not enough to attain the oligotrophic status. This could be because of too much nutrient discharged depending on the intensity of aquaculture activities which were happening at the site but also the ecological conditions such as water current and depth where the cages were installed (Ling et al. 2016). The classification of the site in this study is similar to how the sites on the offshore waters of Barrang Caddi Islands in Indonesia were classified but different from the onshore sites which were classified as hypertrophic despite the sites having cage aquaculture activities in progress at the time of the study compared to this study which was done 6 months to 1 year after abandoning cage aquaculture (Maslukah et al. 2022). The difference could be attributed to variation in environmental conditions between freshwater and marine environments but also location of site, as offshore areas are deep with high water currents hence adequately flushing the organic matter discharged from the cages to maintain the ecological conditions.

Another important observation relates to a decreasing trend of Chl-a with depth throughout the sampling period except for the cage site in the dry season. This is in contrast with what Bootsma et al. (2003) reported that nutrient levels increase with depth on Lake Malawi during upwelling. Phytoplankton activity increases with increase in available nutrient hence increase in nutrient levels with depth could correspond with increased phytoplankton activity but that is not the case with the observation from this study. This may be due to lack of particularly favourable combination of light and nutrient as depth increases (Marañón et al. 2021).

4.3. Association between physicochemical water quality parameters and phytoplankton biomass after cessation of cage aquaculture

Physicochemical water quality parameters such as temperature, turbidity, pH, salinity and dissolved oxygen affect the phytoplankton biomass. Water temperature had a more significant positive correlation with Chl-a than any other variable in this study. These results are different from those reported for Barrang caddi island in Indonesia where total suspended solids was the most associating factor with Chl-a (Maslukah et al. 2022). These differences could be due to variations in limnological conditions between the two studied aquatic environments.

A positive significant association between water temperature and turbidity was observed in this study. This association which has been reported by other researchers has effects on dissolved oxygen concentration in water as high-water temperatures are correlated with low dissolved oxygen because oxygen solubility decreases at high temperatures (Mwamburi et al. 2020). It is not surprising that a significant negative correlation between water temperature and dissolved oxygen but also between turbidity and dissolved oxygen was observed in this study. These observations agree with the negative but significant correlation between dissolved oxygen concentration and Chl-a also revealed in this study.

Total suspended solids showed a significant positive correlation with Chl-a concentration in this study. These findings are similar to Barrang Caddi islands where a positive correlation between TSS and Chl-a was also observed but not as significant as it is in this study (Maslukah et al. 2022). However, the study observed that the most influential water quality parameter was TSS, quite different to the findings of this study as total suspended solid was the second most factor associating positively with Chl-a.

This study also found that there was a negative correlation between Chl-a and turbidity, similar to what was observed in Barrang Caddi islands in Indonesia (Maslukah et al. 2022). The rate of photosynthesis which is inhibited by turbidity can cause a decrease in phytoplankton biomass. While the positive correlation observed in western Barrang Caddi was attributed to inorganic sources, the negative correlation in eastern Barrang Caddi was attributed to organic sources such as high phytoplankton activities. However, this study observed higher phytoplankton activity compared to that reported when cage aquaculture activities were in operation at Maldeco cage aquaculture, suggesting that the increase at the study site is due to non-cage aquaculture activities.

pH significantly correlated negatively with Chl-a in this study. Low pH was observed during the wet season which was also characterized by high phytoplankton activity. These findings are different from what was reported for Kenjeran, Surabaya, East Java in

Indonesia that low pH associates with low primary productivity (Mahenda et al. 2021). They are also contrasting from the positive but very weak non-significant relationship between Chl-a and pH in Barrang Caddi Islands in Indonesia (Maslukah et al. 2022). The differences with this study could be attributed to variation in environmental conditions between freshwater and marine environments. Further to this, high phytoplankton activity could mean that a significant amount of carbon dioxide produced from the respiration of phytoplankton. The reaction of carbon dioxide and water releases carbonic acid which reduces the pH conditions of water.

5. Conclusion

This study demonstrates that the increase in chlorophyll-a (Chl-a) levels at the abandoned cage aquaculture sites may be primarily driven by seasonal variations rather than the direct influence of previous presence of cage aquaculture. The elevated Chl-a during the rainy season highlights the significant contribution of external nutrient inputs, particularly agricultural runoff, to nutrient enrichment in the lake, threatening its trophic status. Overall, the cage aquaculture site is showing signs of biological recovery as some of the physical-chemical parameters like Ammonia are lower than what was previously reported and also comparable to control sites and consistent with historical data from other regions of L. Malawi such as Salima. However, the ongoing nutrient influx from external sources may obscure the effects of this recovery process. In general, these findings also underscore the importance of integrating watershed management into agricultural and environmental planning to protect Lake Malawi, a vital resource for the livelihoods of many Malawians. A fallowing period of six months appears sufficient for noticeable ecological natural recovery at the site, given the scale of cage aquaculture operations since 2003 at Maldeco Aquaculture.

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Authors' contributions

Conceptualization: MAP, AHM; Supervision: AHM, DS; Resource Mobilization: MAP; Data Collection and Investigation: MAP; Materials and Methodology: MAP, AHM, DS; Writing—Original Draft: MAP, OJH, MMC; Data Curation, Software, and Formal Analysis: MAP, MMC, DS; Visualization and Project Administration: MAP, AHM; Validation and Review Editing: AHM, OJH. All authors reviewed and approved the final manuscript for submission.

Data availability statement

All relevant materials are included in this article. Should further information be needed, the author shall provide on request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Afraei Bandpei MA, Nasrolahzadeh H, Rahmati R, Khodaparast N, Keihansani A. 2016. Examining the effects of fish cage culture on phytoplankton and zooplankton communities in the southern coast of the Caspian Sea (Mazandaran Waters– Kelarabad). AJLSR. 4(2):104–117. doi: 10.20286/ajlsr-040293.

Bootsma HA, Hecky RE. 1993. Conservation of the African Great Lakes: a limnological perspective. Conserv Biol. 7(3):644–656. doi: 10.1046/j.1523-1739.1993.07030644.x.

Bootsma HA, Hecky RE, Johnson TC, Kling HJ, Mwita J. 2003. Inputs, outputs and internal cycling of silica in a large, tropical lake. J Great Lakes Res. 29(suppl. 2):121–138. doi: 10.1016/S0380-1330(03)70543-7.

Boyd CE. 1990. Water quality in ponds for aquaculture. Alabama agricultural experiment station, Auburn Univ., Alabama USA. p. 482.

Devi PA, Padmavathy P, Anand S, Aruljothi K. 2017. Review on water quality parameters in freshwater cage fish culture. International Journal of Applied Research. 3(5): 114–120.

El-Serehy HA, Abdallah HS, Al-Misned FA, Irshad R, Al-Farraj SA, Almalki ES. 2018. Aquatic ecosystem health and trophic status classification of the bitter lakes along the main connecting between red sea and the Mediterranean. Saudi J Biol Sci. 25(2):204–212. doi: 10.1016/j.sjbs.2017.12.004.

Gondwe MJS, Guildford SJ, Hecky RE. 2011. Physical–chemical measurements in the water column along a transect through a tilapia cage fish farm in Lake Malawi, Africa. Journal of Great Lakes Research. 37(1):102–113.

Hasimuna OJ, Chibesa M, Ellender BR, Maulu S. 2021. Variability of selected heavy metals in surface sediments and ecological risks in the Solwezi and Kifubwa Rivers, Northwestern province, Zambia. Sci Afr. 12:e00822. doi: 10.1016/j.sciaf.2021.e00822.

Hasimuna OJ, Jere WW, Mtethiwa AH, Yabe J, Chibesa M, Mphande J, Mumbula I, Phiri CJ, Siavwapa S, Nawanzi K, et al. 2024. Assessment of trace elements (Cu, Fe, and Zn) in Limnothrissa miodon from Lake Kariba, Zambia: implications for ecological and human health. J Appl Animal Res. 52(1):2310753. doi: 10.1080/09712119.2024.2310753.

Hasimuna OJ, Maulu S, Monde C, Mweemba M. 2019. Cage aquaculture production in Zambia: assessment of opportunities and challenges on Lake Kariba, Siavonga district. Egypt J Aquat Res. 45(3):281–285. doi: 10.1016/j.ejar.2019.06.007.

Hasimuna OJ, Maulu S, Nawanzi K, Lundu B, Mphande J, Phiri CJ, Kikamba E, Siankwilimba E, Siavwapa S, Chibesa M. 2023. Integrated agriculture-aquaculture as an alternative to improving small-scale fish production in Zambia. Front Sustain Food Syst. 7:1161121. doi: 10.3389/fsufs.2023.1161121.

Holm-Hansen O, Lorenzen C, Holmes R, Strickland J. 1965. Fluorometric determination of chlorophyll. Conseil International Pour L'Exploration de la Mer. J Conseil. 30(1):3–15. doi: 10.1093/icesjms/30.1.3.

Kaunda E, Salima C, Macuine MA, Msiska OV. 2023. Feasibility of cage culture on Lake Malawi, part 1: physical, chemical and biological processes. Eur J Appl Sci. 11(6):294–316.

Langi S, Maulu S, Hasimuna OJ, Kaleinasho Kapula V, Tjipute M. 2024. Nutritional requirements and effect of culture conditions on the performance of the African catfish (*Clarias gariepinus*): a review. Cogent Food & Agri. 10(1):2302642. doi: 10.1080/23311932.2024.2302642.

Ling T, Nyanti L, Nurul-Safinaz MK, Sim S, Grinang J. 2016. Comparisons of water quality near cage culture in Batang Ai reserviour, Sarawak, Malaysia. Iranica Journal of Energy and Environmental Science. 7(2): 169–176.

Ma C, Chula Mwagona P, Yu H, Sun X, Liang L, Al-Ghanim KA, Mahboob S. 2019. Spatial and temporal variation of phytoplankton functional groups in extremely alkaline Dali Nur Lake, North China. J Freshwater Ecol. 34(1):91–105. doi: 10.1080/02705060.2018.1554545.

Macleod CK, Moltschaniwskyj NA, Crawford CM. 2006. Evaluation of short-term fallowing as a strategy for the management recurring organic enrichment under salmon cages. Mar Pollut Bull. 52(11):1458–1466. doi: 10.1016/j.marpolbul.2006.05.007.

Macuiane, M, Hecky, R, Guildford S. 2016. Temporal and spatial changes in water quality in lake Malawi/Niassa, Africa: implications for cage aquaculture management. Oceanography & fisheries Open Access Journal. 1(1): 555552. doi: 10.19080/OFOAJ.2016.01.555552

Mahenda AA, Wiradana PA, Kuncoroningratsusilo RJ, Soegianto A, Ansori ANM, Pradisty NA. 2021. Relationship of water with phytoplankton abundance in Kenjeran coastal waters, Surabaya, East Java, Indonesia. Pollution Res. 40(2):515–521.

Marañón E, Van Wambeke F, Uitz J, Boss ES, Dimier C, Dinasquet J, Engel A, Haëntjens N, Pérez-Lorenzo M, Taillandier V, et al. 2021. Deep maxima of phytoplankton biomass, primary production and bacterial production in the Mediterranean Sea. Biogeosciences. 18(5):1749–1767. doi: 10.5194/bg-18-1749-2021.

Maslukah L, Setiawan R, Nurdin N, Helmi M, Widiaratih R. 2022. Phytoplankton chlorophyll a biomass and the relationship with water quality in Barrang caddi Spermonde, Indonesia. Ecol Eng Environ Technol. 23(1):25–33. doi: 10.12912/27197050/143064.

Maulu S, Hasimuna OJ, Chibesa M, Bbole I, Mphande J, Mwanachingwala M, Nawanzi K, Chibeya D, Siavwapa S, Mbewe J, et al. 2024. Perceived effects of climate change on aquaculture production in Zambia: status, vulnerability factors, and adaptation strategies. Front Sustain Food Syst. 8:1348984. doi: 10.3389/fsufs.2024.1348984.

Maulu S, Hasimuna OJ, Haambiya LH, Monde C, Musuka CG, Makorwa TH, Munganga BP, Phiri KJ, Nsekanabo JD. 2021. Climate change effects on aquaculture production: sustainability implications, mitigation, and adaptations. Front Sustain Food Syst. 5:609097. doi: 10.3389/fsufs.2021.609097.

Muhala V, Chicombo TF, Macate IE, Guimarães-Costa A, Gundana H, Malichocho C, Hasimuna OJ, Remédio A, Maulu S, Cuamba L, et al. 2021a. Climate change in fisheries and aquaculture: analysis of the impact caused by Idai and Kenneth cyclones in Mozambique. Front Sustain Food Syst. 5:714187. doi: 10.3389/fsufs.2021.714187.

Muhala V, Rumieque A, Hasimuna OJ. 2021b. Aquaculture production in Mozambique: approaches and practices by farmers in Gaza Province. Egypt J Aquat Res. 47(1):87–92. doi: 10.1016/j.ejar.2020.11.004.

Mwamburi J, Basweti G, Owili M, Babu J, Wawiye P. 2020. Spatial-temporal trends of nutrients and physical-chemical parameters on lake ecosystem and fisheries prior to onset of cage farming and re-opening of Mbita passage in Nyaza gulf of Lake Victoria. Lakes & Reservoirs. 25(3):292–313. doi: 10.1111/lre.12329.

Simfukwe K, Msukwa AV, Mphande J, Hasimuna OJ, Limuwa MM, Kaunda E. 2024. Is the concentration of heavy metals in sun-dried Engraulicypris sardella (Günther, 1868) in Malawi, a human health risk? Environ Chem Ecotoxicol. 6:354–362. doi: 10.1016/j.enceco.2024.08.002.

Stainton MP, Capel MJ, Armstrong, AJ. 1977. The chemical analysis of freshwater. Canada: Miscellaneous Special Publication; p. 180.

Yee LT, Paka DD, Nyanti L, Ismail N, Emang JJJ. 2012. Water quality at Batang Ai Hydroeletric Reservoir (Sarawak, Malaysia) and implications for Aquaculture. International Journal of Applied Science and Technology. 2(6):23–30.

Zhulay I, Reiss K, Reiss H. 2015. Effects of aquaculture fallowing on recovery of macrofauna communities. Mar Pollut Bull. 97(1–2):381–390. doi: 10.1016/j.marpolbul.2015.05.064.